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A Comparative Study between Different Control Techniques for Speed Control of Induction Motor

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ABSTRACT: In this dissertation, we successfully design and implement the Indirect Field Orientation Method (IOFC) in MATLAB/Simulink for 50hp squirrel cage induction motor (SCIM) and then design Conventional controllers (i.e., PI, PD and PID), Fuzzy Logic Controller (FLC) and hybrid controller (i.e., FLC+PI, FLC+PD, FLC+PID, FPPI). After successful design and implementation of entire controllers, we compare the speed response of Squirrel Cage Induction Motor at different load torque by applying different controllers. The main aim of this paper is to compare the response of different controller without changing any parameter. In my Simulink model all eight (8) controller is connect with a manuals switch. Manually select a controller and study the speed response of the motor. The speed response parameter include rise time (sec), settling time (sec), settling minimum value, settling maximum value, overshoot value, peak value and peak time (sec).

KEYWORD: Induction Motor, Indirect Field Orientation Control (IFOC), Fuzzy Logic Controller (FLC).

I. INTRODUCTION

Induction motors, specially the squirrel cage induction motors (SCIM) is widely use in industry application such as paper and textile mills, hybrid vehicles, robotics, and wind generation system etc, because of their several benefits such as their simple construction, reliability, robustness, low cost, and low maintenance needs. Without proper controlling, it is practically impossible to achieve the desire task for any industrial application. [1]. Induction motor is singly-excited A.C machine in which stator winding is directly connected to A.C supply, where as rotor winding receive its power from stator by means of induction. Maximum power to the rotor is transferred when copper losses become to iron losses i.e. $P_{cu} = P_i$.

Accurate control of electrical machines is achieved by the independent control of torque and magnetic flux. Due to this reason high performance electrical drive systems can easily implement on DC machine. As it is well known that both torque and magnetic flux are easily controlled by rotor and stator currents, so due to this fact in the later eighties, a new control scheme i.e. Direct Torque Control (DTC) scheme has been introduced. [2]. But DTC has its own disadvantage that is placing hall sensors in the air gap of the motor to determination of the direct and quadrature components of the air gap flux vector, this installing sensors in the air gap are inconvenient, and they spoil the ruggedness of the induction motor. So IFOC scheme is frequently use due to implementation simplicity and no any special sensor to introduce in the motor [1] [2]. To achieve optimal efficiency of induction motors, several control techniques have developed to control the induction motor such as scalar control, vector, field oriented control, direct torque control. Scalar control is one of the basic control techniques of speed control of induction motors. In this method the ratio of both the amplitude and frequency of the applied voltage is kept constant to maintain a constant air gap flux and hence obtain maximum torque. Scalar control drives are easy to implement but does not yield satisfactory results for high performance applications. So field oriented control or direct torque control are most use. In most of industrial drive control applications include field orientation method. This method is considered as standard method to control speed of induction motor. Field oriented or vector control principle in order to achieve the best dynamic behaviour. In this method the decoupling between the flux and torque allows the induction motor to be controlled in a similar method to that in the control of separately exited dc motors. Therefore it can be used for high performance applications [1].

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II. INDIRECT FIELD ORIENTATION CONTROL OF INDUCTION MOTOR

The indirect field oriented control consists of controlling the stator currents represented by a vector. This control is based on projections that transform a three phase time and speed dependent system into a two coordinate (d and q frame) time invariant system [8]. IFOC machines need two constants as input references: the torque component (aligned with the q coordinate) and the flux component (aligned with d coordinate).To implement indirect field orientation scheme first uses three-phase currents (a,b,c) i.e., I_{as}, I_{bs}, and I_{cs} transformed into currents in the two-phase orthogonal stator system (d^s,q^s) i.e., I_d^s and I_q^s, i.e, Clark transform. Then this two-phase orthogonal system (d^s,q^s) transform into rotating reference frame (d^e-q^e). i.e, Park transforms [8] [11].

Complete algorithm is given below for indirect field orientation scheme [1][12]:

1. Measure the stator phase currents I_a, I_b, and I_c. These currents are feed to Clarke transformation module that gives two components, I_d^s and I_q^s, in stationary reference frame.
2. Transform the set of these two currents, I_d^s and I_q^s, into rotating reference frame. This conversion called Park transformation, and provides I_d^e and I_q^e.
3. The rotor flux is computed by: $\hat{\Psi}_r = \left(\frac{L_m I_d^e}{1+\tau_r}\right)$ where, $\tau_r = \left(\frac{L_r}{R_r}\right)$.
4. The rotor angle, θ_e, required for coordinate transformation is computed by equation:

$$\theta_e = \left\{\int_0^t (\omega_{sl} + \omega_{act})dt\right\}$$

5. The motor speed (ω_{act}) is compared with the reference speed (ω_{ref}) and the error produced is fed to the speed controller. The output of the speed controller is electromagnetic torque T_e^*.
6. The quadrature stator current component reference is calculated by:

$$I_q^{e*} = \left\{\left(\frac{2}{3}\right)\times\left(\frac{2}{p}\right)\times\left(\frac{L_r}{R_r}\right)\times\left(\frac{\tau_e^*}{\hat{\Psi}_r}\right)\right\}$$

7. The direct stator current component reference I_d^{e*} is obtained by: $I_d^{e*} = \left(\frac{\hat{\Psi}_r}{I_m}\right)$
8. I_d^{e*} and I_q^{e*} current references are converted into I_d^{s*} and I_q^{s*}, current references in stationary reference frame by using inverse Park transformation.
9. I_d^{s*} and I_q^{s*} current references are converted into phase current references I_a^*, I_b^*, and I_c^* by using inverse Clarke transformation and fed to the current controller. After then controller processes the measured and reference currents to generate the gating signals.
SIMULINK model is shown in figure 1.

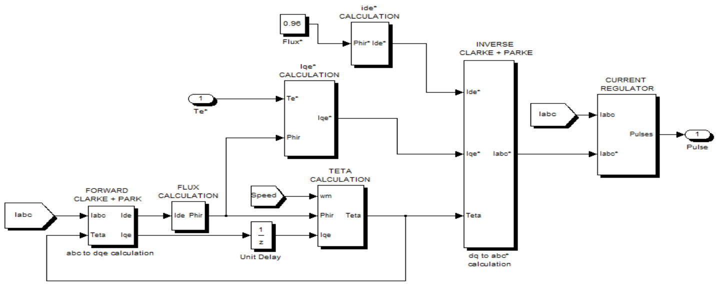
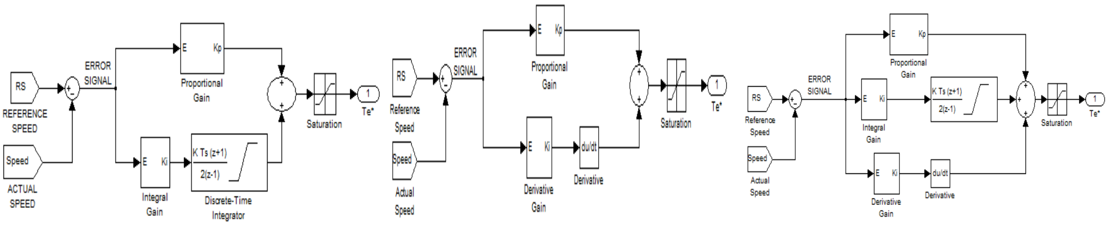


Figure 1:Simulink Model of IFOC scheme.

III. CONTROLLERS

After implementing the IFOC we implement the various controllers. In this IFOC method, by controlling the SCIM output torque, the actual speed response of the SCIM is controlled. But the controlling of torque is varying to controller to controller. Perfect controlling of torque gives output to perfect speed response curve [6] [7]. The various type of controller such as conventional controller i.e. PI, PD and PID, fuzzy logic controller (FLC) and hybrid fuzzy-conventional controller i.e., FLC+PI, FLC+PD and FLC+PID are combining with IFOC to achieve the perfect response of speed curve. The reference speed of 120rad/sec is considered for all controllers. All this controllers are connected with the help of manual switch and select one controller manually at a time, and study the speed response in terms of rise time, settling time, overshoot, undershoot and peak time.

1. Conventional Controller: Conventional controller includes PI, PD and PID as shown in figure 2(a)(b)(c). All these controllers are closed loop/feedback controller along with IFOC. The difference of reference speed (ω_{ref}) and actual speed (ω_{act}), which is called the speed error ($E_{(s)}$), is given as input to the controller. The speed controller processes the speed error and gives torque value as an input. Then the torque value is fed to the limiter, which gives the final value of command torque to IFOC scheme [2] [3].



(a) (b) (c)

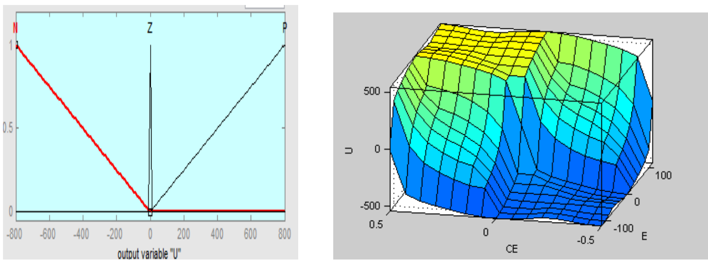
Figure 2: Conventional Controller: (a) PI-controller (b) PD-controller and (c) PID-controller

2. Fuzzy Logic Based Controller (FLC): The design of a Fuzzy Logic Controller requires the choice of Membership Functions. The membership functions should be select such that they cover the whole universe of discourse. It should be taken care that the membership functions overlap each other [7] [6] [1]. This overlapping is done in order to avoid any kind of discontinuity with respect to the changes in the inputs. To achieve perfect/finer control, the membership function near the zero regions should be made narrow as possible as shown in figure 3(b). Wider membership functions away from the zero regions provide faster response to the system. Hence, the membership functions should be adjusted as per your controller performance. After the appropriate membership functions are chosen, a rule base should be created as shown in figure 3(b). It consists of a number of Fuzzy If-Then rules that completely define the behaviour of the system. We implement 9 If-then rules as shown in figure 3(a).

   The inputs to the Fuzzy Logic Controller are:
   1) Speed Error (E).
   2) Change in Error (CE) or derivative of speed error.

   The control output of FLC is torque with maximum value of 800Nm.

CE \ E	NB	Z	PB
NB	NB	NB	Z
Z	NB	Z	PB
PB	Z	PB	PB



(a) (b) (c)

Figure 3(a): Fuzzy rule-base table (b) output membership function (c) Rule view of rule-base for controlling the speed of SCIM.

3. Hybrid Controller: Hybrid controller is the simply a combination of fuzzy logic controller (FLC) with conventional controller i.e. FLC+PI, FLC+PD, FLC+PID and Fuzzy Pre-compensated Proportional Integral

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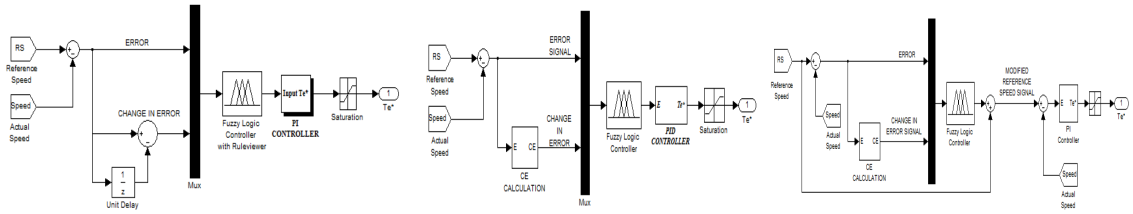
(FPPI) controller [5]. The conventional speed controllers for indirect vector control of induction motor suffer from the problem of stability, these controllers such as PD or PID controllers show steady state error to remove the disadvantages of conventional and FLC i.e., steady-state error, and PI-controller i.e., overshoot and undershoot.



(a) (b) (c)

Figure 4(a): FLC+PI (b) FLC+PID and (c) FPPI Controller.

To take over the advantages present in both FL and PI controllers, a hybridization of FL and PI controllers, called fuzzy Pre-compensated Proportional Integral (FPPI) controller, is done and is used as a single controller. As shown in figure 4(c). In this controller, FL is used for pre-compensation of reference speed, which means that the reference speed signal (RS) is changed in advance in accordance with the rotor speed, so that a new modified reference speed signal is obtained and the main control action is performed by PI controller. Some particular features such as overshoot and undershoot happening in the speed response, which are obtained with PI controller can be removed and this controller is much useful to loads where the torque/speed of the motor varies every moment.

IV. SIMULINK MODEL

A complete SIMULINK model of proposed control system for SCIM is shown in Figure 5. The induction motor used in this simulation is a 50 Hp, 460 V, 60 Hz, squirrel cage. The induction motor stator is fed by a current controlled three-phase inverter bridge. The IGBT/Diode is use as a power electronic element for the 3-phase Inverter Bridge, having 3 bridge arms. The motor speed is regulated by various controllers i.e., PI, PD, PID, FUZZY+PI, FUZZY+PD and FUZZY+PID controller which produce the required torque current component signal. Manual switch is use to select the particular controller. Then the output results of various controllers are comparing.

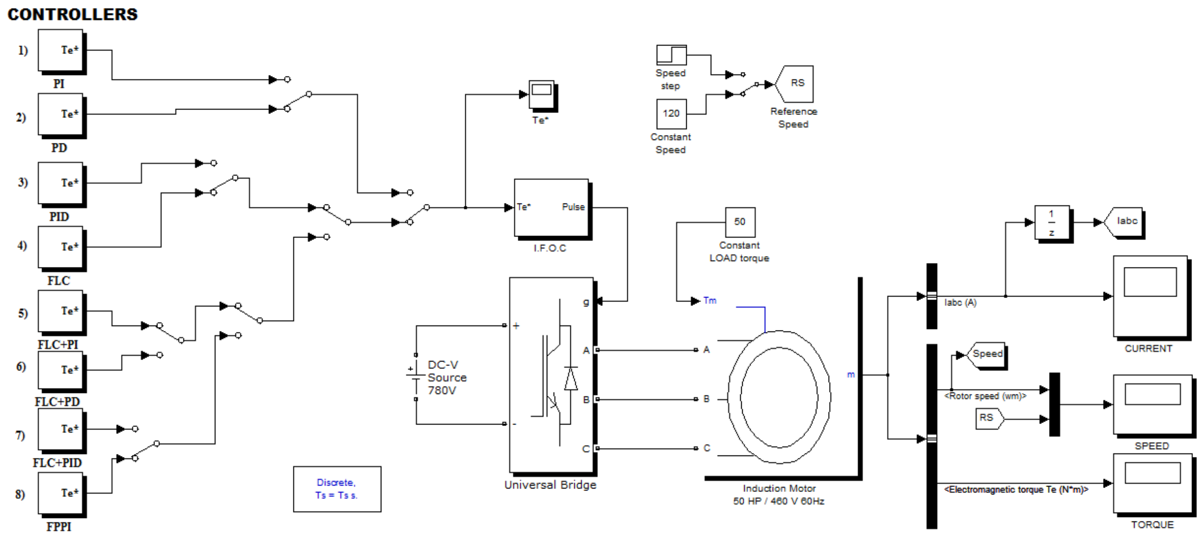


Figure 5: Complete SIMULINK MODEL.

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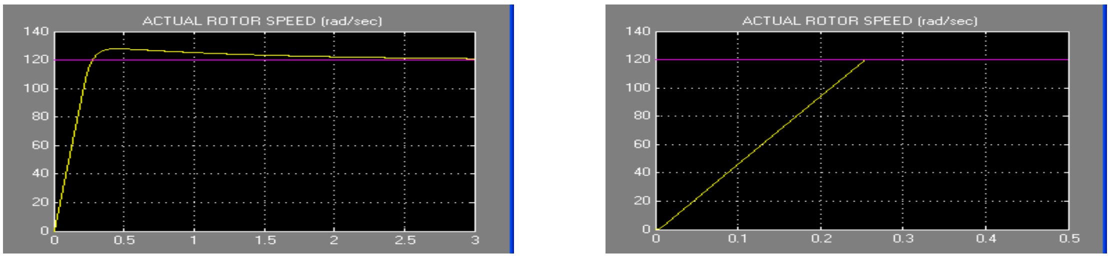
V. RESULT AND DISCUSSION

The performances of all controllers are investigated while varying the load torque values. The maximum output torque is fixed for the entire controller and the other parameter is same for all the controller, only controller is change and according to this response of the controllers are study.

1. Speed response in no load and at reference speed 120rad/sec

The speed responses of SCIM under no load torque and at reference speed of 120 rad/sec. The computing time interval is 3sec for conventional controllers are shown in figure 6(a). And computing time interval for hybrid controllers are 0.5sec shown in figure 6(b) .In these figure pink line represent reference speed and yellow line represent the response curve.



(a) (b)

Figure 6: (a) Speed response of PID controller (b) FLC+PID controller, under NO LOAD.

Controllers	Rise time (sec)	Settling time (sec)	Settling minimum value	Settling maximum value	Overshoot value	Peak value	Peak time (sec)
PI	0.2005	0.9520	108.0059	127.2863	6.0719	127.2863	0.4075
PD	0.2132	0.3396	108.0063	119.5210	0	119.5210	1.1663
PID	0.2010	1.9390	108.0110	127.8670	6.5559	127.8670	0.4566
FLC Only	0.3495	0.4481	108.0027	119.9098	0	119.9098	0.8749
FLC+PI	0.1999	0.2499	108.0141	120.0549	0.0458	120.0549	0.2592
FLC+PD	0.1999	0.2499	108.0141	120.3558	0.2965	120.3558	0.4000
FLC+PID	0.1999	0.2499	108.0141	120.0868	0.0723	120.0868	0.2803
FPPI	0.1999	0.2499	108.0114	120.0547	0.0456	120.0547	0.2587

Table 1: Performance analysis of all controllers at 120 reference speed under NO load condition.

From above simulation results under no load torque condition, we conclude that the motor speed response for conventional controllers shows overshoot and deviation from reference speed and then return to the desire speed after some interval of time. Whereas Hybrid PI, PID and FPPI does not shows overshoot and deviation.

2. Load Torque of 50Nm and Reference Speed of 120 rad/sec

Load of the motor is fixed at 50nm and reference speed is at 120rad/sec. The time of operation for conventional controller is 3sec, whereas for hybrid is at 0.5 sec as shown in figure 7. In these figure pink line represent reference speed and yellow line represent the response curve.

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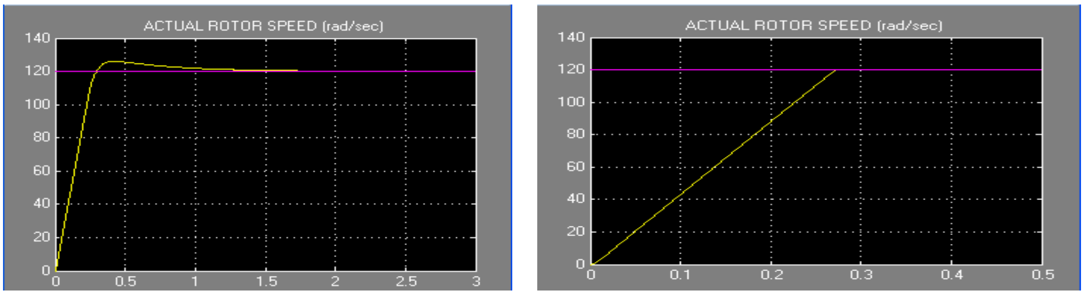

(a) (b)

Figure: 7(a) Speed response of PI-controller (b) FLC+PI controller, in 50Nm constant load torque.

Controllers	Rise time (sec)	Settling time (sec)	Settling minimum value	Settling maximum value	Overshoot value	Undershoot value	Peak value	Peak time (sec)
PI	0.2139	0.8963	108.0093	126.0078	5.0065	0.0358	126.0078	0.4316
PD	0.2289	0.4354	108.0036	117.9989	0	0.0358	117.9989	1.3917
PID	0.2145	1.7255	108.0076	126.4892	5.4077	0.0358	126.4892	0.4844
FLC Only	0.3932	0.5085	108.0004	119.5476	0	0.0359	119.5476	0.6138
FLC+PI	0.2133	0.2666	108.0006	120.0457	0.0381	0.0359	120.0457	0.2781
FLC+PD	0.2133	0.2666	108.0006	119.6760	0	0.0359	119.6760	0.5000
FLC+PID	0.2133	0.2666	108.0006	120.0407	0.0339	0.0359	120.0407	0.3266
FPPI	0.2133	0.2666	108.0030	120.0454	0.0379	0.0358	120.0454	0.2788

Table 2: Performance analysis of all controllers at 120 reference speed under 50Nm load torque.

We can easily notice that the motor speed response, under LOAD TOQUE condition, of conventional controller shows overshoot and deviation from reference speed. Whereas the hybrids PI, PID and FPPI controllers are fast response compare to conventional controllers and it does not shown overshoot and any deviation.

VI. CONCLUSION

This paper has successfully presented a Conventional and Hybrid controller for controlling a 50hp three-phase squirrel cage induction motor. We conclude that Hybrid controller has showed the combined advantages of a conventional controller and a FLC. Hybrid controller gives better performances in terms of rise time, overshoot, undershoot and settling time. Hybrid controller include FLC+PI, FLC+PID and FPPI having good response, but hybrid FLC+PD having peak time response is slower than other hybrid controller. Good torque response is obtained with hybrid controller at all time instants and speed response is better than FLC and PI controllers.

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